Human Capital Accumulation and Imbalance Effects in R&D-based Growth Models

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1. Introduction

This paper develops a multi-sectoral endogenous growth model, that is able to reproduce the most important features of an "ICT (Information and Communication Technologies)-based economy", in which a central role is played by human capital accumulation. Indeed, one of the aspects of the so-called "New Economy" (in which ICT are a key element) is that human capital can be of great importance, since education is crucial in acquiring the knowledge necessary to use the new technologies, and at the same time an increase in these technologies makes it easier to accumulate human capital.

The model presented considers discrete time with infinite horizon, endogenous growth, horizontal differentiation and human capital accumulation. In particular, the essential aspects of an ICT economy that it takes into account are the embodied nature of technological progress (typically the innovations that are present in the ICT sector are embodied in the new capital goods), the central role of R&D (since the amount of resources devoted to it is high, particularly in the USA) and the link between innovation and market power (because ICT markets are non-competitive), in addition to the role of human capital accumulation. The model builds on Romer (1990) and Boucekkine and de la Croix (2003) for the general structure, but departs from them in some respects. In particular, the R&D sector assumes the "lab-equipment" specification (Rivera-Batiz and Romer, 1991), furthermore a human capital accumulation activity of the kind introduced by Lucas (1988) is considered.

2. The model

The economy described in the model consists of 4 sectors:

- **the final good sector**: it produces a composite good (used to consume or to invest in physical capital) using efficient capital (bought from the equipment sector) and human capital;

- **the equipment sector**: it produces efficient capital (sold to the final good sector) using physical capital (hardware) bought from the final good producers and immaterial capital (software) bought from the intermediate good producers;

- **the intermediate good sector**: it produces immaterial capital (software, sold to the equipment sector) using human capital;

- **the R&D sector**: it researches for new varieties of immaterial capital, in order to expand their range.

Furthermore, there is a representative household that consumes, saves for future consumption, supplies human capital for production activities and accumulates human capital by devoting a fraction of its time to non-productive activities (schooling).

Starting from this framework it is possible to solve the optimization problems of the different sectors, to derive the equilibrium conditions, to analyse the balanced growth path and then to obtain explicitely the growth rates of the different variables. It turns out that they depend only on technological and preference parameters, furthermore the growth rate of production doesn't depend neither on the absolute dimension of the economy (i.e. its total human capital stock) nor on the population growth (that is equal to zero). As a consequence, an important property of the model is that it doesn't display any "scale effect". Finally, it is possible to obtain the steady state system of the model, from which some analytical results concerning the effects on growth of different shocks that can interest the economy can be found. These results show in particular that permanent changes in the productivity of the final good sector, in the productivity of the equipment sector and in the productivity of the intermediate good sector do not affect the long run growth rate of the economy, while it is affected by the productivity of schooling, that therefore in this model is the true engine of growth. In this case it is also possible to obtain analytically a negative relation between the elasticity of substitution (that is also a measure of competitivity) and the growth rate of the economy, so that it is possible to conclude that an increase in the monopoly power (i.e. a reduction in the elasticity of substitution) increases growth. Other papers, starting from the assumption that the engine of growth is the continuous improvement of the quality level of the existing goods, conclude that product market competition is unambiguously good for growth. The present study shows that this is no longer true considering an horizontal differentiation model of endogenous growth where firms invent new varieties of intermediate goods but, at the same time, the true engine of growth is represented by human capital accumulation. In this case, in fact, the relation between competition and growth reverses.

These are the main results that can be derived analytically from this model, while other insights can be obtained through numerical simulations. This requires a calibration, and in order to do this the values of the different parameters are chosen in such a way that the model is able to reproduce the most relevant empirical data available. Starting from this benchmark situation, then, different issues are studied resorting to simulations.

3. The results of the simulations

A first issue that is considered consists in studying how the economy reacts to different shocks, both in the short run and in the long run. It turns out that an increase in the productivity of the final good sector and a decrease in the cost of a new variety of software, on the one hand, and an increase in the productivity of the equipment sector and an increase in the productivity of the intermediate good sector, on the other hand, have similar consequences. In particular, in all these cases there are no effects on long term growth (as obtained analytically), but only in the short run. On the contrary, an increase in the productivity of schooling produces also long run effects on growth, since the accumulation of human capital through education is the true engine of growth in this model.

A second issue of interest is the link between competitivity and growth; since analytically it has been obtained an inverse relation in the long run between these two quantities, it is possible to study how this relation works in the short run and which are the mechanisms that explain it.

A third issue that can be studied through simulations is the presence of "imbalance effects" with reference to some variables. A deep analysis of this topic is presented in Barro and Sala-i-Martin (1995), and the typical imbalance emerges considering the relationship between the growth rate of output and the ratio K/H (physical capital/human capital). The central idea is that when the value of this ratio is different from the steady state value (in particular, when it is lower), the growth rate of the economy is higher than the rate we have in correspondence of the steady state value of the same ratio. More precisely, considering a one-sector model in which physical and human capital are produced by the same technology, the growth rate of output rises with the magnitude of the gap between the ratio K/H and its steady state value, generating an imbalance effect that is symmetric (i.e. higher growth rates of output emerge if either K or H is in relatively short supply). Considering a more realistic two-sector model in which physical and human capital are produced by different technologies (with the production of human capital that is relatively intensive in human capital) the conclusions change, since it is possible to show that the growth rate of output now tends to rise with the magnitude of the imbalance between the ratio K/H and its steady state value if human capital is relatively abundant, but tends to decline (or to rise more slowly) with the magnitude of the imbalance if human capital is relatively scarce, so that there is now an asymmetric imbalance effect.

With reference to this aspect, in the model developed it is possible to study the presence of imbalance effects relatively to the ratio K/H (physical capital/human capital), to the ratio K/RD (physical capital/R&D expenditure) and to the ratio H/RD (human capital/R&D expenditure). The results obtained show that in all these cases the growth rate of output rises with the magnitude of the imbalance when the ratios considered are below their steady state values, while it rises more slowly with the magnitude of the imbalance when the same ratios are above their steady state values, confirming in all the three cases the presence of an (asymmetric) imbalance effect. These results have some implications on the growth process, for instance considering the situation of underdeveloped countries. These countries are characterized by the presence of low levels of human capital and of R&D expenditures, hence the ratios K/H and K/RD are high. According to the results obtained, the corresponding growth rates of output are lower than the values that would prevail if the same ratios were smaller, hence these countries will grow at lower rates than countries starting from higher levels of human capital and of R&D expenditures, and they will not be able to reach the latter.

4. Extensions of the model and conclusions

The last aspect considered is represented by some extensions of the basic model. The first one is the introduction of the notion of "broad output", a concept used by Barro and Sala-i-Martin (1995) in their analysis of imbalance effects. Indeed, measured output can be broadened to include gross investment in human capital multiplied by an appropriate shadow price of human capital, and broad output is therefore defined as the sum of narrow output and the value in units of goods of the gross investment in human capital. Using this notion it is then possible to derive the relationship between the growth factor of broad output and the ratio K/H. The result is that the growth factor of broad output tends to be a monotonically decreasing function of the ratio between physical and human capital (exactly as obtained by Barro and Sala-i-Martin, 1995): when the ratio K/H is below its steady state value the growth rate of broad output rises with the magnitude of the imbalance, while when this ratio is above its steady state value the growth rate of broad output declines with the magnitude of the imbalance. Also introducing the notion of broad output, therefore, an asymmetric imbalance effect is present in the model.

The second extension that can be considered is the introduction of different types of subsidies. In particular, it is possible to introduce subsidies on R&D, on physical capital accumulation or on human capital accumulation. Considering a subsidy on R&D it turns out that the growth rates of the various quantities don't change with respect to the basic model introduced above, so that this kind of subsidy desn't have significative effects on growth, neither in the short run nor in the long run. Considering the introduction of a subsidy on physical capital accumulation, similarly, it turns out that this measure doesn't have any effect on growth, neither in the short run nor in the long run. Finally, considering the introduction of a subsidy on human capital accumulation (that, in this model, is the true engine of growth), it turns out that, in the short run, the growth rate of output rises with respect to the basic model, and therefore this last kind of subsidy has a positive effect, in the short run, on the growth of the economy.

The third extension of the model that can be studied consists in considering the productivity of human capital (i.e. of schooling) as a function of technological progress, in order to have a link between human capital accumulation and technological progress, that is typical of ICT (since new technologies can allow people to be more educated). Also in this case it is then possible to derive the relationships between the growth factor of output and the ratios K/H, K/RD and H/RD, and this analysis shows that the imbalance effects continue to be present also in this version of the model, and they are asymmetric, since the growth rate of output is higher when the ratio considered is below its steady state value, while it declines when this ratio is above its steady state value.

In conclusion, the model proposed, that considers R&D activity with horizontal differentiation and human capital accumulation in order to reproduce some central aspects of an ICT-based economy, gives the following main results:

- the presence of scale effects is excluded;
- the productivity of schooling affects the long-run growth of the economy, while the productivities of the other sectors don't have this effect;
- a positive relationship between market power and growth can be found;
- imbalance effects originate in the economy;
- the introduction of subsidies on R&D and on physical capital accumulation doesn't have any effect, while the introduction of subsidies on human capital accumulation has, in the short run, a positive effect on growth.

All these results are important and allow to shed more light on the properties of an economy in which the new technologies play a central role.

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